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SAVING STEAM IN INDUSTRIAL HEATING SYSTEMS

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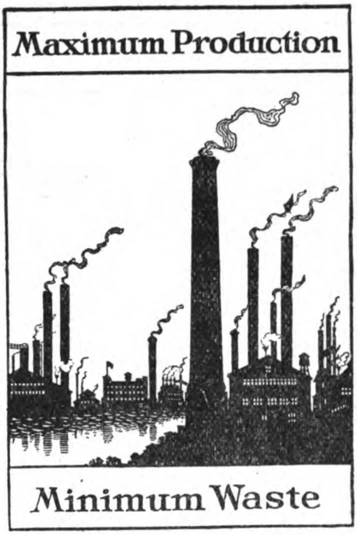

A source of easily preventable loss incurred by many factories is that of the use of live steam for heating and for other purposes where exhaust steam would be at least as satisfactory. The manner in which the exhaust-steam problem is handled constitutes the greatest single determining factor in the economy of a steam plant. This bulletin calls attention to some faults of design and operation which lead to such an uneconomical use of live steam and describes the means for correcting them.

UNITED STATES FUEL ADMINISTRATION.

SAVING FUEL IN INDUSTRIAL HEATING SYSTEMS.

Large economies are frequently possible in heating a factory. There are many steam-heating systems which consume from two to three times the volume of steam required, due to one or more causes. For instance, using steam for heating directly from the boiler while wasting enough exhaust steam to supply all heating demands.

Assuming that we have a heating system taking steam at the rate of 3,000 pounds per hour directly from a boiler, under a pressure of 125 pounds gauge, we can, by installing an engine operating at a 30-pound water rate, develop 100 indicated horsepower and still leave in the steam about 92 per cent of its original heat (see figs. 1 and 2).

By supplying directly from the boiler the slight additional amount of steam needed for heating we gain 100 horsepower at the cost of a very slightly increased fuel consumption.

It often happens that a smaller total quantity of steam is used by a properly proportioned engine and heating system operated together than when the engine is not running and the heating demand is supplied by live steam direct from the boilers. The smaller steam consumption with the engine is due partly to the fact that the heating system, designed for the lower temperature, has too large a radiating surface for the hotter live steam, and there is waste through over-

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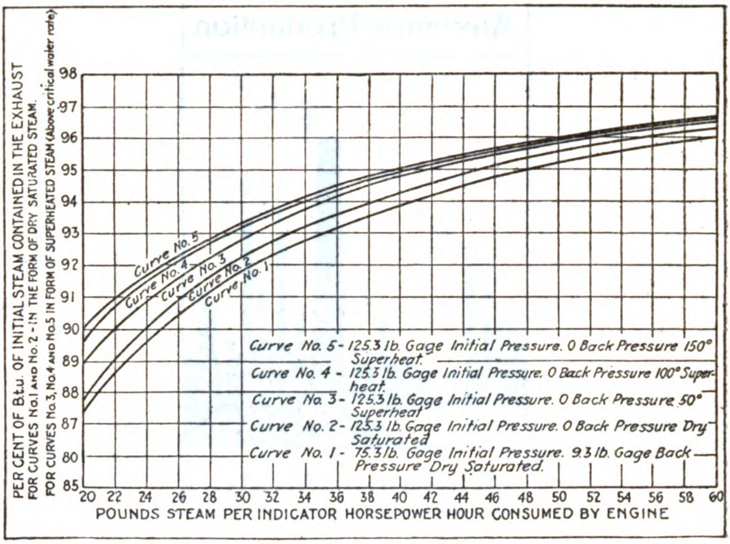

Fig. 1.

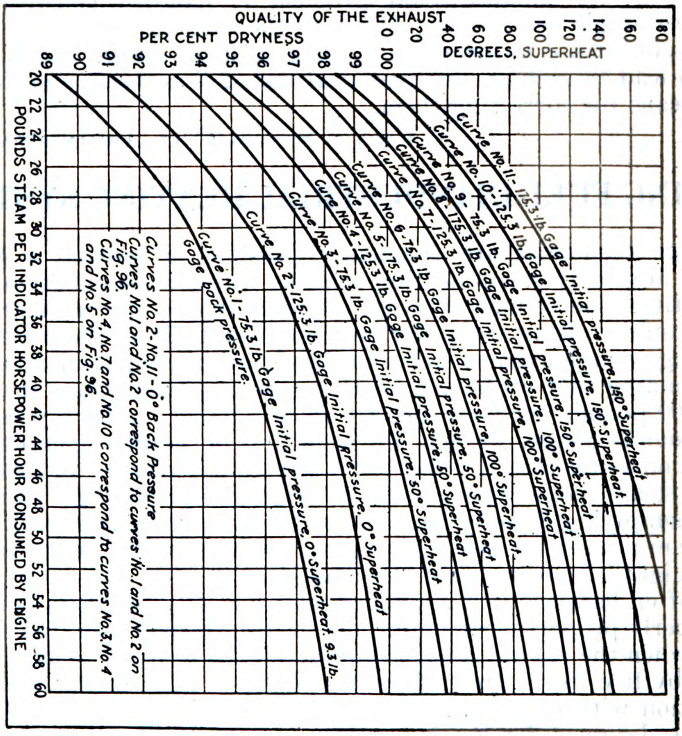

Fig. 2.

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heating. The re-evaporation loss later discussed is also greater with higher pressure steam.

Managers and owners have a decided tendency to undervalue the heat content of exhaust steam. Taking the average type of noncondensing factory engine, it is safe to state that over 90 per cent of the heat supplied at the throttle is available for heating purposes in the exhaust steam. The less efficient the engine, pump, or turbine, the greater the percentage of heat contained in its exhaust.

Poorly designed heating systems are responsible for the needless use of live steam to correct faulty circulation, but it is always possible to substitute exhaust for live steam, where poor circulation is the cause of the trouble, by suitably modifying the piping system.

Of course, we can not heat anything either by live or exhaust steam to a temperature higher than that of the steam itself, so that what really limits the use of either live or exhaust steam is the temperature corresponding to the steam pressure maintained.

Transfer of heat from the steam to the air or any other substance can occur only when the substance is at a lower temperature than that of the steam, and the rapidity of heat transfer increases as the temperature difference between the two bodies increases. Where the pressure, and, therefore, the temperature of the steam is low, a larger amount of radiating surface is required than for the transmission of the same amount of heat by means of high-pressure steam. But it will often be found that low-pressure exhaust steam can be substituted for high-pressure live steam without increasing the amount of radiating surface, provided the original system is susceptible of improvement in the matter of circulation. In a case of this kind exhaust steam at one-half pound gauge pressure substituted for live steam at 20-pound gauge actually increased the heating effect.

Bad circulation may be caused by inefficient draining of condensation, steam piping of restricted area and complicated lines, air binding of radiators, etc.

CHIEF REQUIREMENTS FOR A GOOD LOW-PRESSURE HEATING SYSTEM.

The chief requirements for a good low-pressure heating system are:

1. Removal of oil from exhaust steam.
2. Free circulation of steam with least possible pressure drop from the engine to the radiators.
3. Continuous and effective removal of air and condensation from coils and radiators.
4. Prevention of escape of steam from radiators.
5. The return of all condensation to the feed-water heater. Such a system is later described in fuller detail.

Very great waste of steam occurs through inefficient steam traps for discharging from radiator units the condensation and air and for preventing the escape of uncondensed steam. Due to insufficient care and supervision and badly designed traps large quantities of steam are discharged into the drip lines, with a consequent waste of fuel *sometimes amounting to 200 per cent of the amount required under efficient conditions.* Oftentimes radiators are found without traps, and hand regulation of the drip valve is depended upon, usually resulting in much waste.

Several forms of traps are shown and described in figs. 3, 4, and 5.

When high-pressure steam is used in heating coils an additional waste ordinarily results from a reevaporation of a part of the condensed water in the coil upon its discharge through the trap into a lower pressure. This water is practically of the same temperature as the high-pressure steam in the coil, so that when it passes into the lower pressure of the return line a portion of it, depending in amount upon the difference in temperature between the two lines, evaporates into steam which is of no service for heating.

It is possible, however, by a special piping and trap arrangement to conserve this reevaporation for use in the low-pressure portion of the heating system of the plant. Such a plan is shown in figure 6.

SOME REPRESENTATIVE TYPES OF STEAM TRAPS.

Figure 3 shows a steam trap representative of the "bucket" type. The discharge is intermittent. The condensation gradually fills the space around the bucket and then flows into it, causing it to sink to the bottom, thereby opening the valve and allowing the pressure to force the condensation out through the discharge. This restores the buoyancy of the bucket and closes the discharge valve.

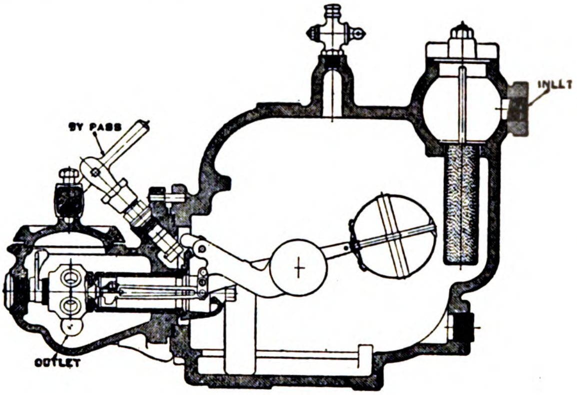

Fig. 4.

Figure 4 shows a steam trap illustrating the float principle. It is designed for continuous discharge of condensation. As water accumulates beyond a definite level the float causes the discharge valve to open.

Figure 5 shows a gravity or weighted type of steam trap. Its discharge is intermittent. When sufficient condensation has accumulated in the globe the counterweight is overbalanced, causing the trap to tilt, thus opening the discharge valve.

There are many modified forms of the three types of steam traps illustrated. Some of these known as "lifting" traps discharge the condensation, even when handling low-pressure steam, at a considerable elevation. This is accomplished automatically, admitting over the accumulated condensation direct steam from the boilers, and simultaneously opening the discharge and closing the connection to the low-pressure returns.

Traps are also designed for returning condensation direct to the boilers by means of an arrangement which automatically equalizes the steam pressure within the trap and within the boiler, so that if the trap is set above the water level in the boiler the action of gravity causes the condensation to flow into the latter. It is economical to return the hot condensation from all heating coils to the boilers, both to save distilled water and to conserve fuel, but the value of exhaust steam compared to that of the hot returns is often misunderstood, so that very large losses in heat and fuel continue without correction.

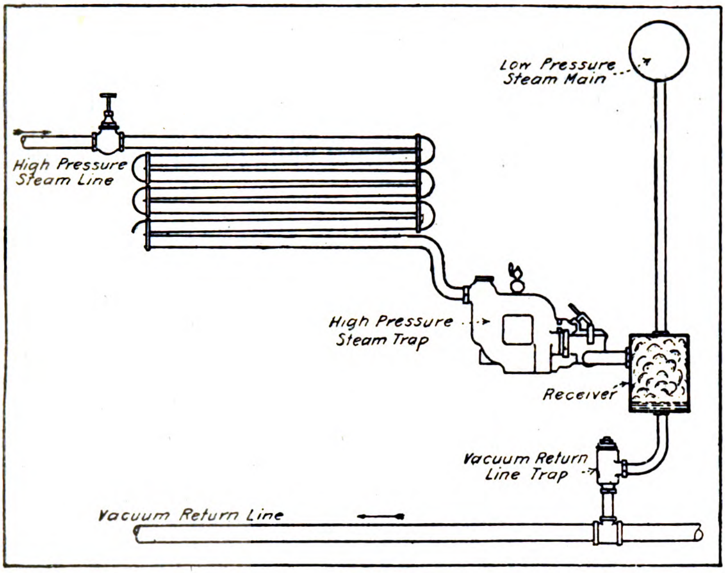

Fig. 6.

Where exhaust steam is substituted for live steam the saving will be approximately eight times that of returning an equal weight of hot drips.

A false impression exists that much less fuel is required to generate steam at low pressure than at high pressure, but as steam at 151 pounds gauge has only about 4 per cent more heat than steam at 1 pound gauge pressure, the fuel required in the two cases varies but slightly.

The amount and percentage of heat lost by reevaporation may be calculated as per following example:

Assume pressure of steam in radiator, 20-pound gauge.

Then temperature of steam and water in radiator equals 259°.

If the discharge of condensation is to atmospheric pressure at a temperature of 212°, the hot water discharged from the radiator will give up heat by evaporation until its remaining water portion is cooled to 212°.

Heat in 1 pound steam at 20-pound gauge	1,167 B. t. u. above 32°
Heat in 1 pound water at 259 degrees	228 B. t. u. above 32°
Heat in 1 pound water at 212 degrees	180 B. t. u. above 32°
Heat in 1 pound steam at 212 degrees	1,150 B. t. u. above 32°

Let x equal weight of water evaporated into steam. (1,150—180) $(1-x)$ equals 212°.

The waste by reevaporation is therefore 0.0495 × 1,150 B. t. u., equals 57 B. t. u. per pound of steam supplied to the radiator, which, since the heat in the water below the room temperature is not available, would give:

$$\frac{57}{1,167-70-32} \text{ equals 5.05 per cent as the percentage waste.}$$

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RATE OF HEAT TRANSFER.

This is expressed by the amount of heat transferred per hour, per square foot of radiating surface per degree of temperature difference between steam and air.

The rate of transfer from radiators depends partly on their form; the rate increases with increasing difference of temperature between steam and air and also with the velocity of air passing over the radiating surface. In still air this rate is nearly 1.8 British thermal units per hour with a temperature difference of 142°, but several times this value when the air is forced at high velocity over the radiating surface, as in the blast coil heaters of indirect systems.

Therefore, this type of heating apparatus requires only a fraction of the radiating surface required in a direct heating system.

In water heating by means of steam coils a more rapid transfer of heat obtains. In an ordinary closed type of feed water heater this amounts to about 180 British thermal units per square foot per hour per degree temperature difference.

DIRECT AND INDIRECT HEATING SYSTEMS COMPARED.

To return to the heating of air, a brief comparison of the two principal systems may be made.

The *direct* system comprises a number of radiators of steam coils located in such a way as to give the desired distribution of heat. Mains and branch lines of piping connect these radiating units to the source of steam supply and another piping system serves to collect the hot condensation and return it to the feed water heater of boilers. The regulation of heat is governed by numerous valves attached one to each of the units throughout the plant. These valves are regulated usually by hand, but may be designed for automatic control by means of a thermostatic device. A well-designed direct system is economical of steam and for many sets of factory conditions is more satisfactory.

The *indirect* or blast coil system comprises a fan arranged either to force or induce a current of air through a bank of tubes containing steam and set in a housing from which the heated air is distributed in pipes or flues to the desired locations. Return flues may be specified whereby the warm air after its first use is returned to the fan inlet for reheating and continued circulation.

The *indirect* system provides a positive method of ventilation of the buildings and rooms. A specified number of air changes per hour can be effected both summer and winter and in the warm months the air may be cooled by a water spray arrangement, thus producing more efficient working conditions for the employees. An engine or motor is required to drive the fan and the volume of air the degree of heating or conditioning are under centralized control in the power plant. The amount of radiating surface is much smaller than with the direct system, and drip piping is short and does not extend out of the power plant department. There are no radiators at distant points, the valves of which might require the attention of the engineering staff. The cost of installation may be either more or less than the direct system, depending upon requirements. The steam consumption of the blast system is greater usually than that of the direct system, owing to the fact that generally more air is heated with a greater number of air changes per hour. Furthermore, a great waste occurs in constantly heating a fresh supply of cold air unless a very efficient return duct system is planned and intelligently used. A direct-connected steam engine forms an excellent drive for the fan, owing to ease of speed regulation, although a variable speed motor may often be employed. The exhaust from the fan engine is generally piped into the blast-heating coils, where it may be efficiently utilized in cold weather, providing there is not already a surplus of exhaust in the plant.

The handling of the heating problem in conjunction with the power plan of a factory has a greater influence on the over-all economy than any other feature of the design and operation. Where a steam plant is used the following rules must be strictly adhered to:

1. Never, if you can avoid it, produce more exhaust steam than can be used at all times of the year, day and night.
2. If noncondensing units can not be utilized for the power requirements which will at the same time conform to rule 1, then operate noncondensing units only for such time, periods, and load as will just balance the heating demand, and have a unit or units of the most economical type to carry the balance of the purely power load. The same effect may sometimes be obtained by use of a bleeder type of steam turbine. Sometimes the most economical units for power only may be oil or gas engines.
3. *Never use live steam for a purpose to which exhaust steam can be applied.*
4. If a plant contains noncondensing units only, maximum efficiency is obtained when the production of exhaust is equal to or less than the heating demand, but never when an excess of exhaust is produced. When less exhaust is made than the quantity wanted, it is proper to draw live steam from the boilers to supply the deficiency.

For computing the heat required to warm buildings we must know or assume how much air per hour must be heated, and to the heat thus computed we must add that required to care for the heat lost by radiation through building walls and windows.

For approximating the condensation to be expected in direct low-pressure radiation we may compute one-third to one-half pound per square foot of surface per hour under what may be termed average conditions. If the tested consumption of steam is much greater, we may look for inefficiency in the system, unless the conditions impose an unusual demand through low outside temperature or a large number of air changes.

A high combined efficiency of power and heating may, in some cases, be effected by employing a special system of hot-water radiation. The water is passed through a closed heater inserted in the exhaust line between the prime mover and the condenser. The vacuum on the condenser is varied as more or less heat is required by the radiation. Thus when but little heating is needed a high vacuum is carried on the condenser. As the demand for heat increases the condenser vacuum decreases until atmospheric pressure is attained when all of the exhaust is used for heating. In this manner the regulation of the vacuum controls the temperature and heat available for the water, which is circulated through the system of radiation.

In laying out the heating design for any industrial plant the first consideration should be the heating of the boiler feed water with exhaust steam. Then the balance of the exhaust should be applied to the remaining uses. If the water for boiler feed has an initial temperature of 60°, about one-seventh (1/7) of the total boiler output after passing through and performing work in simple engines will be condensed in heating the feed water to a temperature of 212°. In a condensing plant the exhaust from the auxiliaries, if properly specified, can be made to balance this requirement. Where no other heating is wanted, the danger is always that of producing too much rather than too little exhaust for the needs.

SEPARATING OIL FROM RETURN FEED.

An important requirement in connection with the heating system is the separation of oil from the hot water returned to the feed-water heater and boiler. Failure in this regard will probably result in burning, bagging, or blistering the boiler tubes or shells. Two methods of elimination are possible, and it is generally advisable to employ both.

1. Extract the oil from the steam by use of oil separators inserted in the exhaust piping. Separators should never be specified by the size of the exhaust pipe but by the quantity in pounds of steam per hour to be cleansed of oil. The ordinary baffle-plate type of separator is a very inefficient device. Better forms are those employing a reservoir to retard the velocity of the steam and permit time for precipitation of the oil.

2. The second way to remove oil from the feed water is by filtration. Several makes of good oil filters or grease extractors are on the market which may be inserted in the feed line between the pump and the boiler. Some open-type feed-water heaters include a filter as part of the apparatus and this may materially assist in the elimination of oil from the water.

It is apart from the present purpose to treat in detail the various types of steam-heating systems, but since one type in particular has proved highly efficient for factory low-pressure heating work, a description of its operation will be of value. It will be noted that it provides for those features which have been specified as essential to efficiency. The plan we now refer to is known as the vacuum return lines system. It is shown complete in all its essential parts in the accompanying illustration (fig. 7). Its object is to insure a positive circulation of the steam to all portions of the radiators, to near and distant units alike; to obviate the necessity of carrying heavy back pressures on the engines, to produce this circulation, thus effecting pronounced gains in efficiency and capacity of the prime movers; to remove automatically from radiators all condensation and air as they accumulate and to prevent waste of uncondensed steam.

In addition to these features it is common practice to so arrange a regulating valve that when the pressure in the heating main falls below a predetermined standard, indicating a deficiency of steam for heating, this regulating valve will open sufficiently to make up the shortage by admission of live steam direct from the boilers.

Referring to the illustration, the exhaust from the engine leads directly into the feed-water heater giving the first preference of the steam to the heating of the feed water. Combined with the feed-water heater is an oil separator to cleanse the steam before its contact with the feed water or its entrance into the heating system. The balance of the steam, not condensed by heating the feed water,

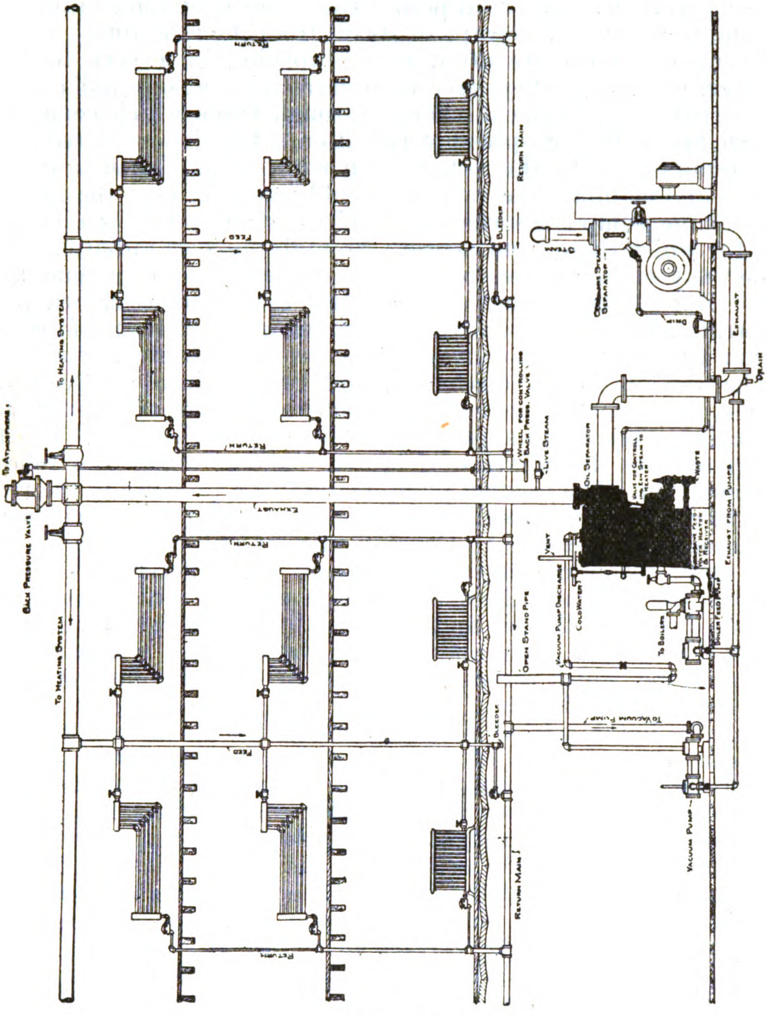

Fig. 7.

flows upward to a back-pressure valve which is set to maintain the pressure required for the operation of the heating system, and to discharge to the atmosphere any steam excess. In ordinary practice, the back pressure may be as little as zero to 1-pound gauge at the engine though with very long exhaust mains it may be necessary to carry slightly heavier back pressures. At a point between the feed-water heater and the back-pressure valve, branch mains carry the steam supply for its distribution to the various units of radiation. Each radiator or coil is equipped with a hand or automatically regulated-inlet valve and has a vacuum return-line valve at its lowest point which connects with the return-drip system leading back to the vacuum pumps shown on the cut. The function of the vacuum return-line valve, which operate on different principles according to their make, is to permit the removal of condensation and air and to prevent the escape of steam from the radiators.

Vacuum systems are often found working in a very inefficient manner, even after they have been correctly laid out and installed. The usual cause is the discharge through traps which connect the return line with high-pressure radiation. The action of reevaporation occurs and fills the return main with steam. Then in order to regain and maintain the vacuum, a cold-water jet near the intake of the vacuum pump is inserted to " kill " the steam. This is a bad practice for which there is no excuse. No high-pressure radiation should under any circumstances be directly connected to a vacuum-return line. But it may always be indirectly connected as shown in the illustration in figure 6, in which arrangement the steam of reevaporation is separated and conveyed to a low-pressure steam main.

The vacuum pump discharges and returns into the feed-water heater, into which is connected a cold-water make-up supply, automatically governed to supply any deficiency in the feed. The feed pump receives this mixture of heated make-up water and reheated condensation. The vacuum pump maintains a pressure in the return lines of considerably less than atmospheric. (An 8 to 10 inch vacuum is the common practice.) Consequently, if only atmospheric pressure exists inside of the radiators, there is a difference of pressure between the inlet and the outlet of each vacuum return valve which acts to discharge the air and condensation from the radiator. Between the vacuum pump and the feed-water heater is a vented tank or standpipe, which serves to free the air from the hot returns before entering the heater.

Each radiator acts as a condenser for the steam supplied to it and causes a reduction of pressure within itself as long as the air and water are continuously removed. This reduced the pressure in the radiators, which may be atmospheric or slightly less, causes a free inflow of steam through their regulating valves and reduces to a minimum the pressure required in the supply main to cause the necessary circulation of the steam. The result is a minimum back pressure on the engine with the attendant economy in its operation.

Figure 7 illustrates the working principles of all vacuum systems, though a wide variation is possible in the layouts and the details of design. One of the chief variations found is in the type of vacuum valves employed, of which there are two distinct classes: First, those whose operation is actuated by floats; and, second, those which act upon the principle of the thermostat. One of each class is shown in figures 8 and 9. There are, in addition, valves constructed on other principles. For example:

In one type of vacuum return line valve, the air is removed through the small annular space around the stationary stem, which also acts as a guide to the float. The latter rises and opens the discharge valve as the water accumulates (fig. 8).

In one form of the expansion or thermostatic type of vacuum valve, the expansion member contains a volatile liquid, which renders more sensitive its response to changes of temperature (fig. 9).

Since the air is heavier than the steam in a radiator, it tends to sink to the bottom and is, therefore, conveniently removable with the water of condensation, by a trap properly designed for the purpose.

The distinguishing feature of the vacuum return-line system, as compared with ordinary two-pipe systems, is that in the latter the pressure difference required for circulation is above the atmosphere and, therefore, imposes a back pressure in the return lines and with radiators made to act as efficient condensers the back pressure is on the engine or turbine; whereas, with the vacuum system the reduced pressure in the return lines and with radiators made to act as efficient condensers the back pressure on the engine may be reduced to a minimum.

The proper application of the vacuum return-line system may frequently reduce the back pressure sufficiently to increase the capacity of the engine 10 to 20 per cent with a consequent saving of steam. But the greatest saving is likely to be in cases where its use permits the substitution of exhaust for direct steam.

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